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Phonological and semantic processing during comprehension in Wernicke's aphasia: An N400 and Phonological Mapping Negativity Study

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ABSTRACT

Comprehension impairments in Wernicke's aphasia are thought to result from a combination of impaired phonological and semantic processes. However, the relationship between these cognitive processes and language comprehension has only been inferred through offline neuropsychological tasks. This study used ERPs to investigate phonological and semantic processing during online single word comprehension.

EEG was recorded in a group of Wernicke's aphasia n = 8 and control participants n = 10 while performing a word-picture verification task. The N400 and Phonological Mapping Negativity/Phonological Mismatch Negativity (PMN) event-related potential components were investigated as an index of semantic and phonological processing, respectively. Individuals with Wernicke's aphasia displayed reduced and inconsistent N400 and PMN effects in comparison to control participants. Reduced N400 effects in the WA group were simulated in the control group by artificially degrading speech perception. Correlation analyses in the Wernicke's aphasia group found that PMN but not N400 amplitude was associated with behavioural word-picture verification performance.

The results confirm impairments at both phonological and semantic stages of comprehension in Wernicke's aphasia. However, reduced N400 responses in Wernicke's aphasia are at least partially attributable to earlier phonological processing impairments. The results provide further support for the traditional model of Wernicke's aphasia which claims a causative link between phonological processing and language comprehension impairments.

1. Introduction

Wernicke's aphasia (WA) is an acquired syndrome associated with impaired auditory language comprehension in the presence of spared speech fluency (Goodglass et al., 2001a). In this study we use event related potentials (ERPs) to explore the timecourse of online single word comprehension in WA and control participants, and provide insights into the causes of auditory comprehension impairments in this population.

Computational, neuropsychological and neurobiological models of single word comprehension, although different in components and mechanisms, agree on two fundamental stages of comprehension: auditory-phonological and semantic analysis (Hickok and Poeppel, 2007; Marslen-Wilson, 1987; McClelland and Elman, 1986; Norris and McQueen, 2008). Auditory-phonological processing forms the initial stages of comprehension in which the phonological form of the item is abstracted and analysed from the speech stream. Contemporary neurobiological models emphasise a hierarchical processing mechanism in which invariant phonological information is extracted from the acoustic signal by combining increasingly complex units of auditory information (Bizley and Cohen, 2013; Giordano et al., 2012). In the final, semantic processing stage, conceptual representations are accessed and analysed in context (Hagoort et al., 2004).

At the group level, WA is associated with damage to the superior and middle aspects of the posterior temporal lobe. In almost all cases the lesion extends beyond these core regions into inferior temporal, parietal and even frontal regions; however, involvement of these regions is inconsistent (Bogen and Bogen, 1976; Ogar et al., 2011; Robson et al., 2012a, 2012b). The left superior and middle temporal lobe are involved in acoustic-phonological processing and semantic analysis in neurotypical populations (Arsenault and Buchsbaum, 2015; Humphries et al., 2014; Krieger-Redwood and Jefferies, 2014; Xu et al., 2013), an observation consistent with the impairment profile observed in WA. Individuals with WA present with impairments of processing

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Table 1
Participant diagnostics.

		BDAE-Short Form							
	Pt No.	Comp. Centile	Rep. Centile	Fluency	sWPM	Imaging		Pt. No.	ACE-III
WERNICKE'S APHASIA	1	28	5	100	*37*	Clin MRI	CONTROL	1	93
	2	25	30	100	*44*	Clin CT		2	87
	3	7	35	100	*34*	Clin CT		3	91
	4	33	10	55	*29*	NA		4	91
	5	9	7	42	*31*	3T MRI		5	88
	6	13	5	100	*41*	Clin CT		6	88
	7	67	60	100	46	3T MRI		7	94
	8	50	80	100	*42*	Clin MRI		8	88
								9	89
								10	95

BDAE = Boston Diagnostic Aphasia Examination (Goodglass et al., 2001a, 2001b); sWPM = spoken word-picture matching, *italicised* font indicates outside normal limits; ACE-III = Addenbrooks Cognitive Examination (Hsieh et al., 2013); Pt = participant. NA not available.

non-verbal auditory information in tasks such as frequency modulation detection, gap detection and frequency sweep discrimination (Divenyi and Robinson, 1989; Fink et al., 2006; Robson et al., 2013) and phonological analysis, as measured by auditory discrimination tasks (Blumstein et al., 1977; Robson et al., 2014). Additionally, multimodal semantic impairments have been identified in the majority of WA cases using tasks such as semantic association, colour-picture matching, drawing from memory and synonym judgement (Cohen et al., 1980; Gainotti et al., 1983; Robson et al., 2012b).

In recent work, we have demonstrated a significant relationship between phonological discrimination/auditory judgement tasks and language comprehension in WA participants (Robson et al., 2012a, Robson et al., 2013). These results provide support for the traditional model of WA, which hypothesises that disrupted acoustic-phonological processing impairs access to the semantic system (Luria, 1976; Luria and Hutton, 1977). On this view, impairments to the auditory ventral stream following left hemisphere superior temporal lesions disrupt the ability of the auditory network to engage in normal hierarchical processing (Robson et al., 2014; Teki et al., 2013). Therefore, auditory input to the semantic system may be noisy or poorly elaborated/abstracted, leading to difficulties in accurately accessing semantic representations. This type of perceptual access deficit is compounded in those individual with semantic impairments, who are less able to use top-down conceptual constraints to disambiguate such impoverished input.

Lesion and neuropsychological evidence suggests a central role of impaired auditory and phonological processing to the comprehension impairment in WA. This relationship, however, has only been identified through correlations between *offline* neuropsychological assessments, which have different processing requirements to the dynamics of online comprehension. As such, it is important to identify how phonological and semantic components are engaged during on-going, active comprehension. The high temporal resolution of ERPs provides a window into language comprehension as processing unfolds.

Two ERP components are of interest in the current study: the Phonological Mapping Negativity (PMN), alternatively discussed as the Phonological Mismatch Negativity, and the N400. The PMN is a negative deflection in the ERP waveform which occurs approximately 250 ms post-stimulus onset in fronto-central regions (Connolly and Phillips, 1994; Connolly et al., 1992; Desroches et al., 2008; Newman et al., 2003; Steinhauer and Connolly, 2008), and is elicited when the phonological onset of a spoken word does not match the contextually expected phonology (Desroches et al., 2008; Newman et al., 2003). Therefore, this component provides an index of the accuracy of phonological analysis and the early phase of comprehension. It should be noted that a similar early ERP negativity observed during auditory has alternatively been identified as the N200, a component also associated with auditory word recognition processes but interpreted as a reflection of early lexical-semantic processing (Van Den Brink et al., 2001). The N400 is associated with the later semantic processing stage and peaks in central-parietal regions between 200 and 600 ms after stimulus onset (Kutas and Federmeier, 2011). The N400 is thought to indicate the ease of integrating semantic information into context (Baggio and Hagoort, 2011; Friederici, 2011) and/or retrieval of information from semantic memory (Baggio and Hagoort, 2011; Brouwer and Hoeks, 2013; Kuperberg, 2016). The magnitude of this component is modulated by two competing forces. Smaller N400s are found when semantic judgements are easier - a pair of congruent stimuli will elicit a smaller or no N400 in comparison to a pair of incongruent stimuli, because semantic analysis and access is easier in the first instance. The magnitude of the N400 is also reduced under degraded listening conditions (Aydelott et al., 2012; Carey et al., 2014; Strauß et al., 2013), an effect thought to reflect the reduced quality of the information reaching the semantic system (Aydelott et al., 2006).

In this study we explore PMN and N400 responses in a group of individuals with WA and a group of control participants in order to investigate the phonological and semantic components of online language comprehension. We employ a word-picture verification task to investigate how the phonological and semantic systems respond to degrees of acoustic, phonological and semantic competition.

2. Method

2.1. Participants

Ethical approval was obtained from the University of Reading Ethics Committee. Eight individuals with Wernicke's-type aphasia (WA, mean age 66.4, SD 8.2, mean pure tone audiometry threshold 22.5, SD 14.0) and 10 age and peripheral hearing matched controls (mean age 67.6, SD 14.4, mean pure tone audiometry threshold 28.4, SD 17.4) were recruited from a panel of research volunteers. Control participants were screened using the ACE-III (Hsieh et al., 2013) to confirm typical ageing (Table 1).

2.2. WA neuropsychological profile and lesion profile

Individuals with WA were screened using the Boston Diagnostic Aphasia Examination – Short Form (Goodglass et al., 2001b) (Table 1), which was used in conjunction with the clinical opinion of a speech and language therapist to confirm diagnosis. Individuals displayed highly fluent speech, with the exception of P4 and P5, who had somewhat reduced fluency. All individuals displayed impaired language comprehension at the phrase and sentence level, and all but P7 displayed single word auditory comprehension impairments. All individuals displayed some difficulties with repetition, producing phonological errors. Therefore, all individuals presented within the fuzzy boundary of WA but